High Temperature Thermal Energy Storage Development at DLR

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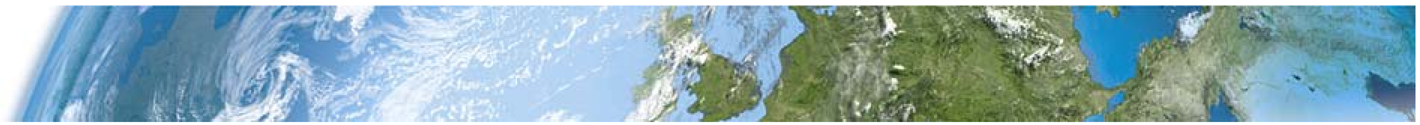
DLR

Outline

- Introduction / Motivation
- Phase change media (PCM) storages
- Compressed air energy storages (CAES)
- Cell-Flux storage concept
- Conclusions / Outlook

Source: Solar Millennium



Introduction / Motivation

Technical options for thermal energy storages in CSP plants

Heat Transfer Fluid	Collector System	Pressure	Temperature
synthetic oil	trough/Fresnel	15 bar	400°C
saturated steam	tower/Fresnel	40 bar	260°C
superhaeted steam	trough/Fresnel	50-120 bar	400-500°C
molten salt	tower/trough	1 bar	500-600°C
air	tower	1 bar	700-1000°C
air	tower	15 bar	800-900°C
new concepts			

storage system

Heat Engine
ORC
steam turbine
gas turbine
Stirling engine
others

ONE single storage technology will not meet
the unique requirements of different solar power plants

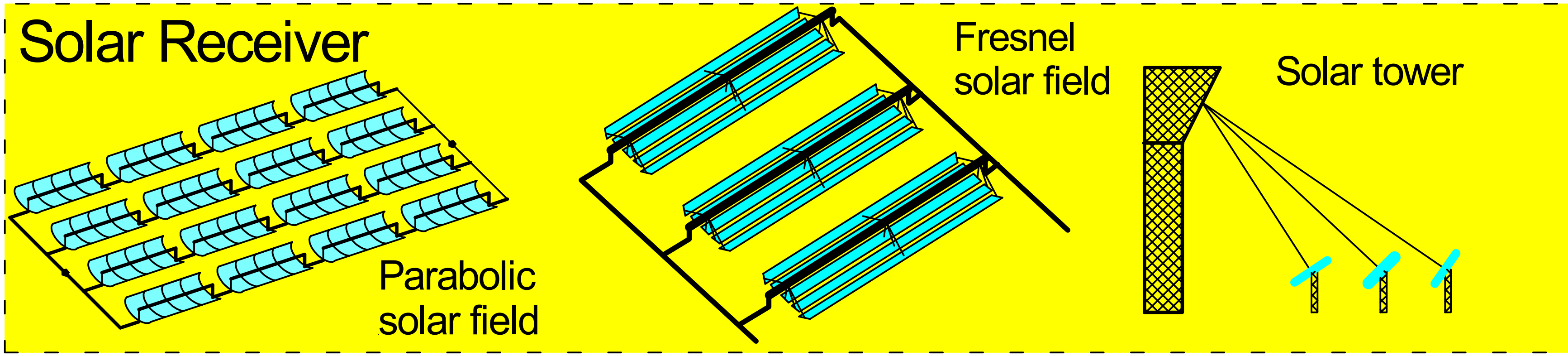
Introduction / Motivation

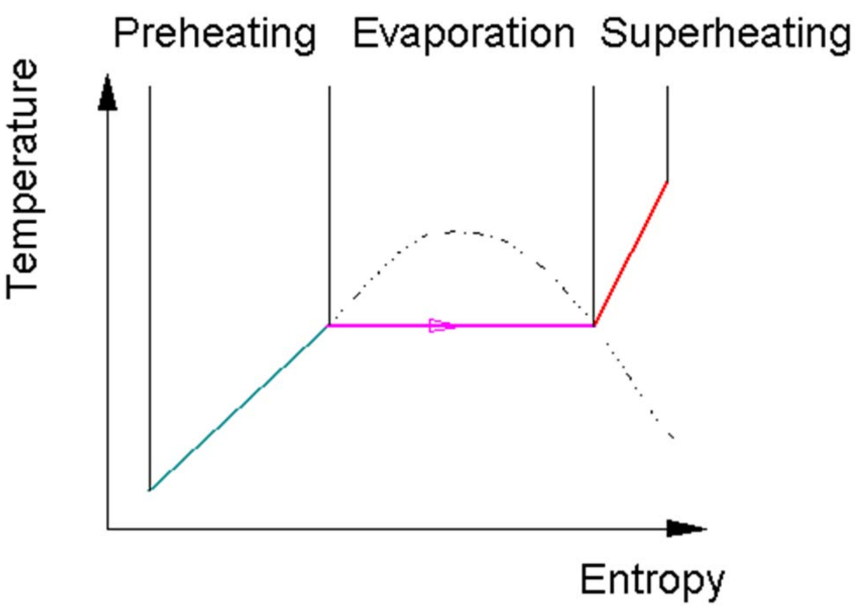
Thermal energy storages under Development at DLR

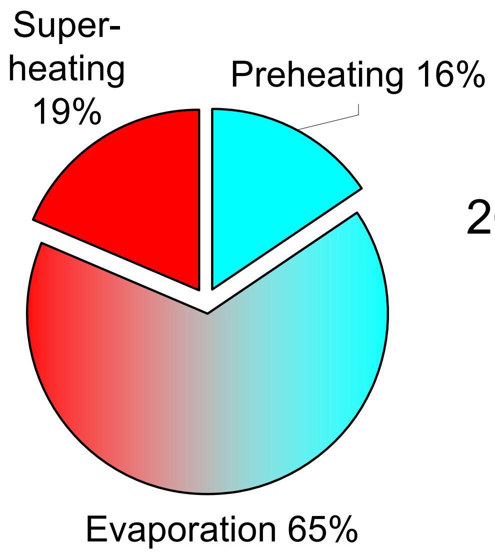
- Sensible heat storages
  - Molten Salt
  - Concrete
  - Regenerator Storages → CellFlux Concept; Compressed Air Energy Storages
- Latent Heat Storages
  - Phase Change Media → Nitrate Salts
- Thermochemical Storages
  - Limestone

Phase change media (PCM) storages

Fundamentals





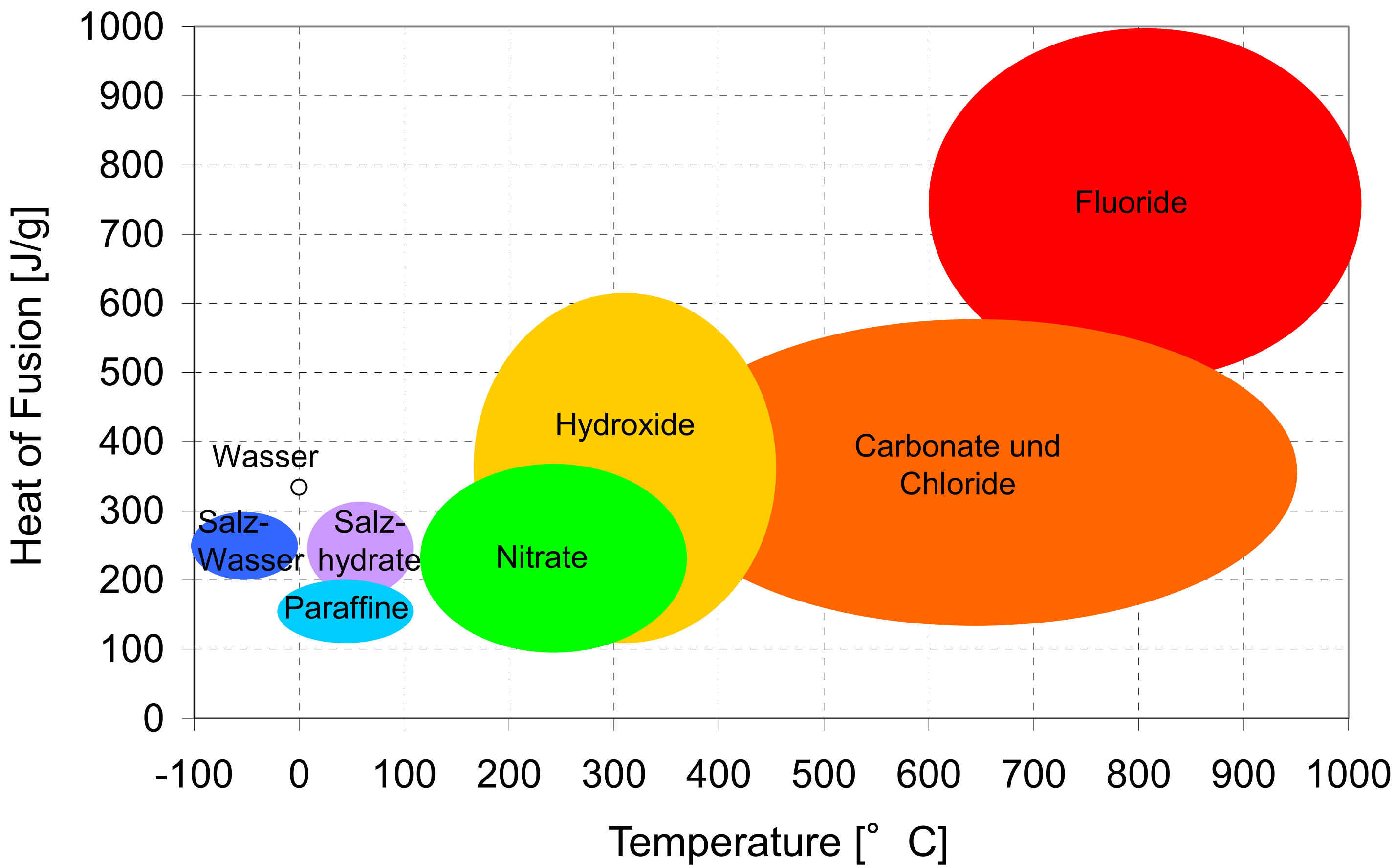


260°C – 400°C

107 bar

Phase change media (PCM) storages

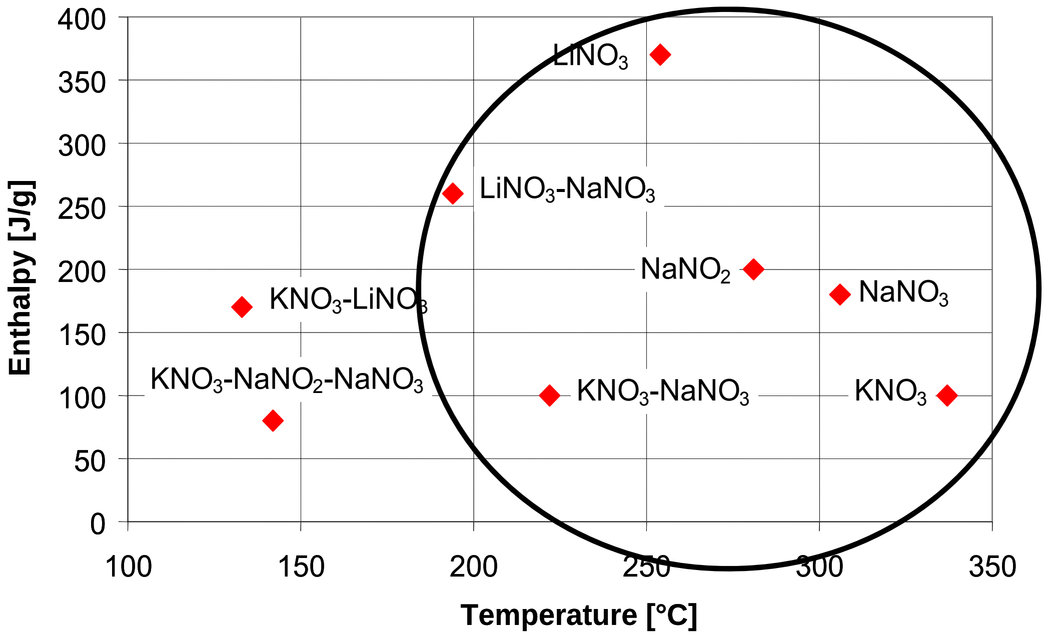
Fundamentals



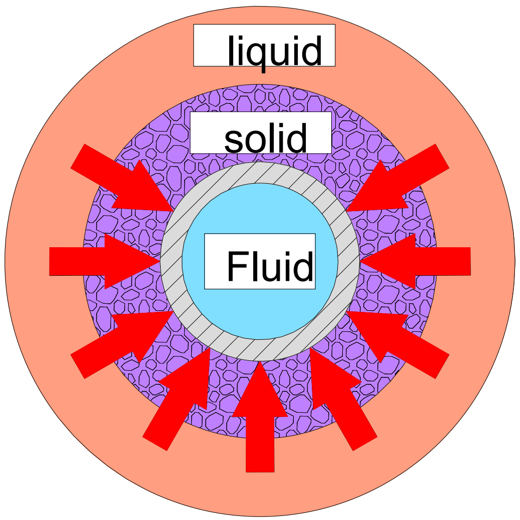
Phase change media (PCM) storages

Current Materials

- Nitrate salt represent possible PCMs for applications beyond 100 ° C
- Important PCM criteria: thermal conductivity, melting enthalpy, thermal stability, material cost, corrosion, hygroscopy

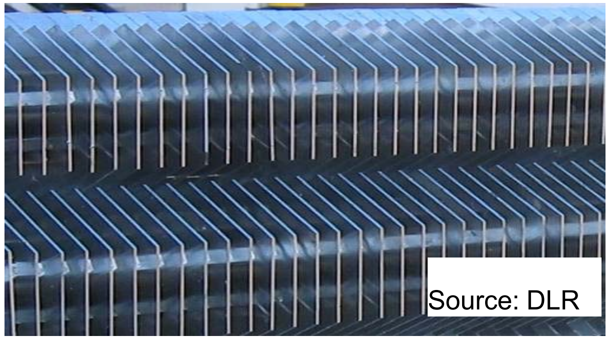


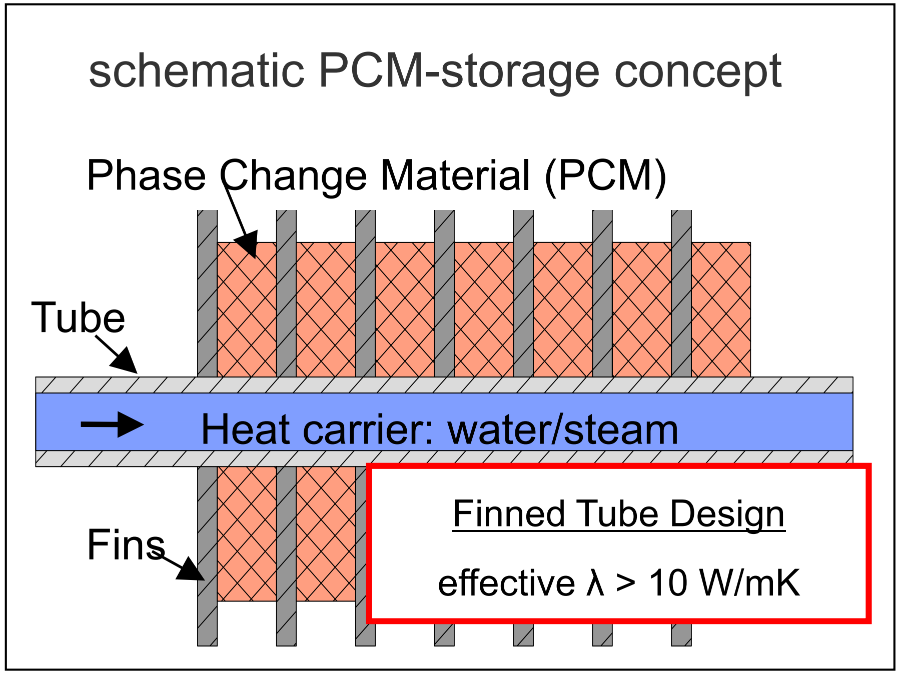
Phase change media (PCM) storages
Challenges



Heat transfer coefficient is dominated by the thermal conductivity of the solid PCM

→ Low thermal conductivity is bottleneck for PCM





Phase change media (PCM) storages

Development of Prototypes

Phase change media

Demonstrated at DLR:

- $NaNO_3$ - KNO_3 - $NaNO_2$ 142°C
- $LiNO_3$ - $NaNO_3$ 194°C
- $NaNO_3$ - KNO_3 222°C
- $NaNO_3$ 306°C

Experimental validation

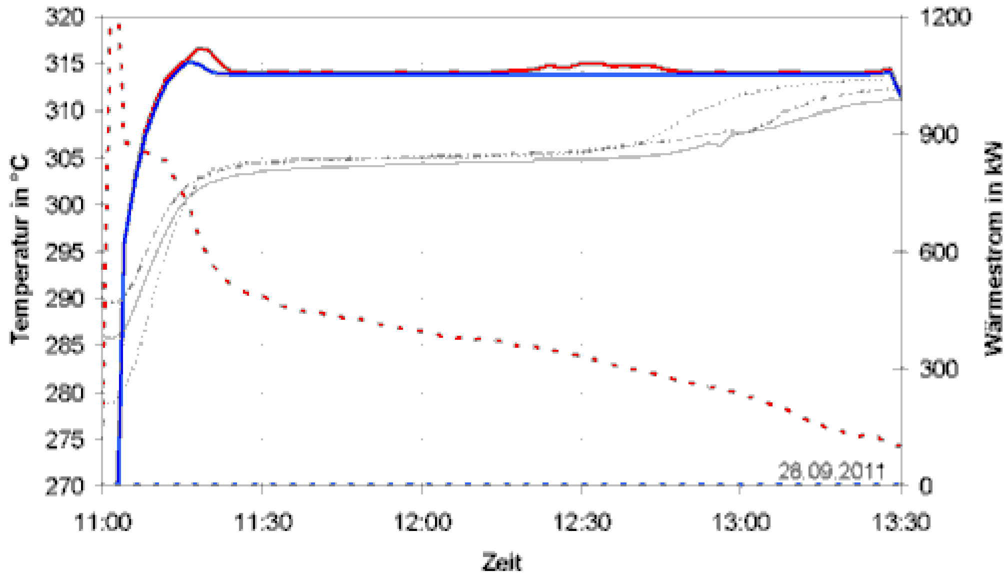
- 5 test modules with 140 – 2000 kg PCM
- Worlds largest high temperature latent heat storage with 14 tons of $NaNO_3$ (700 kWh) operating 2010-11

Phase change media (PCM) storages

Latest Demonstrator

PCM-Evaporator module:

- Capacity ~ 700 kWh
- PCM: $NaNO_3$
- Melting point: 306°C
- Salt volume: 8.4 m³
- Total height 7.5 m
- Inventory ~ 14 t



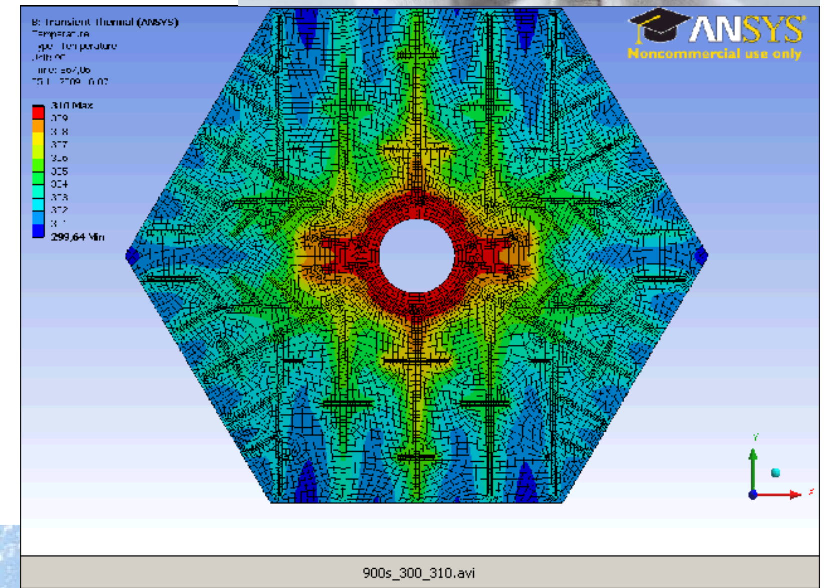
Phase change media (PCM) storages

Current Developments at DLR

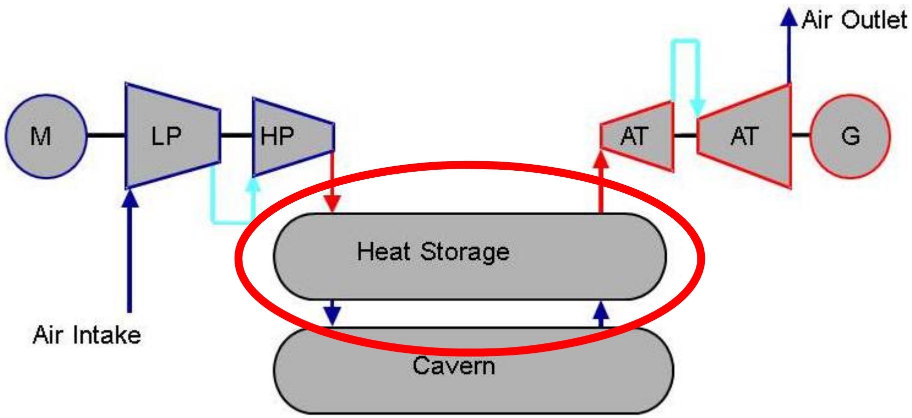
Enhanced heat transfer by extruded longitudinal fins

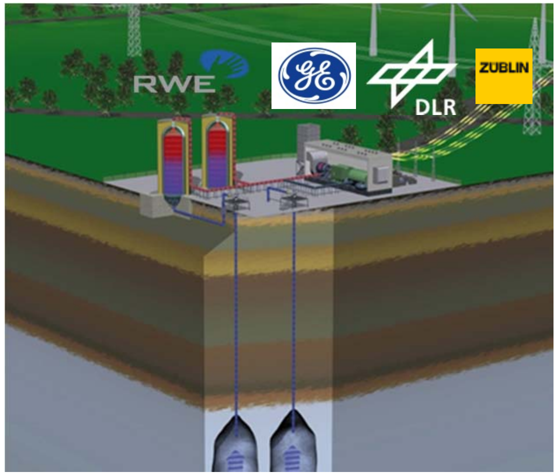
- Cost-effective production and assembly
- Free flow path in vertical direction
  => no risk with volume change during phase change
- Controlled distribution of heat in the storage
- Concept optimized by FEM analysis
- Successful demonstration in lab-scale
- Major cost reduction expected

Source: DLR



Compressed Air Energy Storages (CAES)
Fundamentals





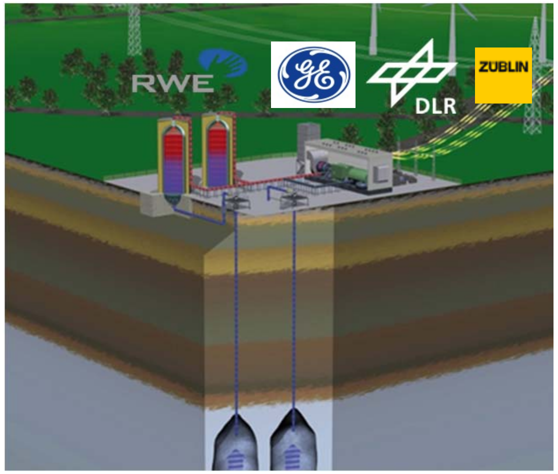
Objectives:

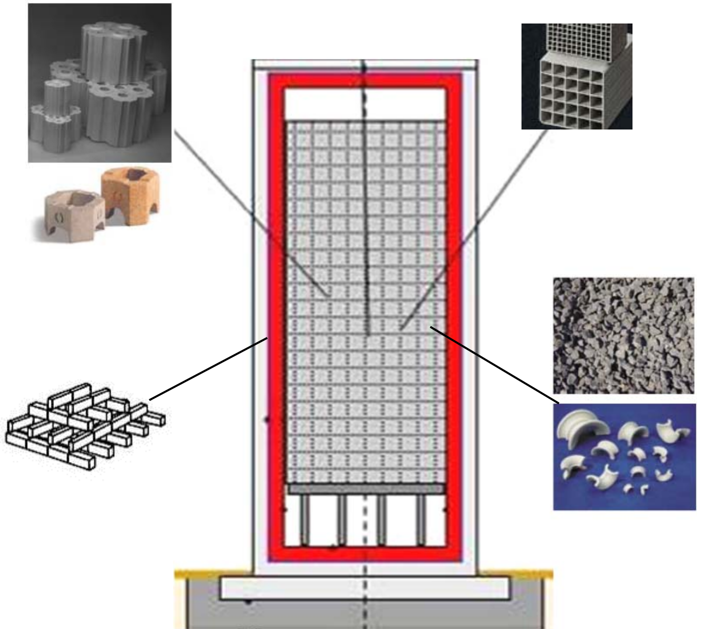
- Peak load/Reserve power 300 MWel, 4-8 turbine full load hrs.
  -> supports grid integration of RE
- Highly efficient due to storage-based heat management
  -> ~70% storage round-trip efficiency
- TES technology: Direct contact solid media storage („regenerator storage“)
- Specifications: ~600 ˚C @60 bar
- Design aspects:
  best heat transfer, fast start-up, efficient solutions for HT-insulation, solutions for pressurised containment, durability of materials in hot & humid atmosphere

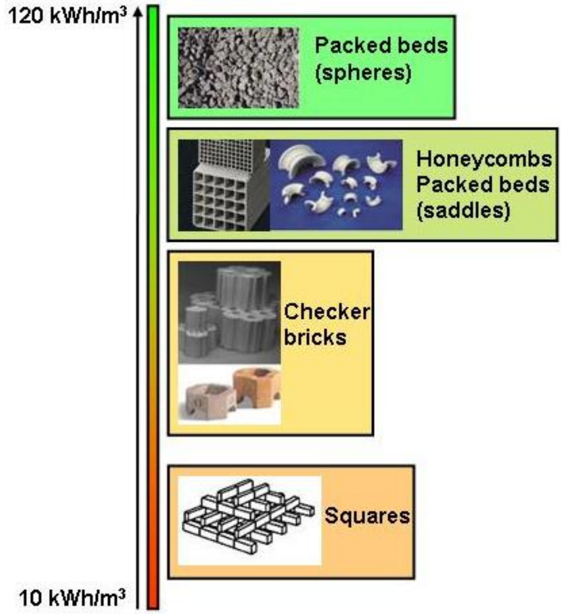
Compressed Air Energy Storages (CAES)

Chosen Concept

- Direct contact between HTF and storage medium
- High temperature applications, simple setup
- Broad choice of applicable inventory materials
- Typical setup: stacked bricks, packed beds allow cost reduction
- Challenges: Thermo-mechanical aspects (packed beds), fluid-dynamic aspects, durability/erosion, containment



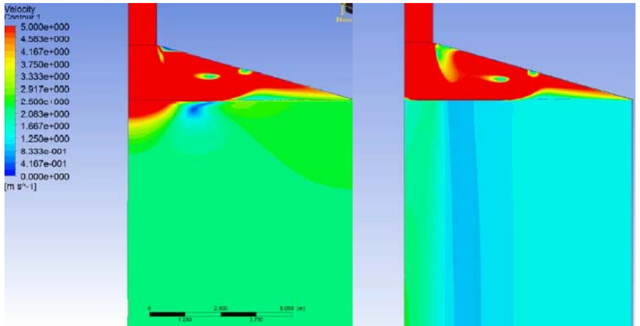


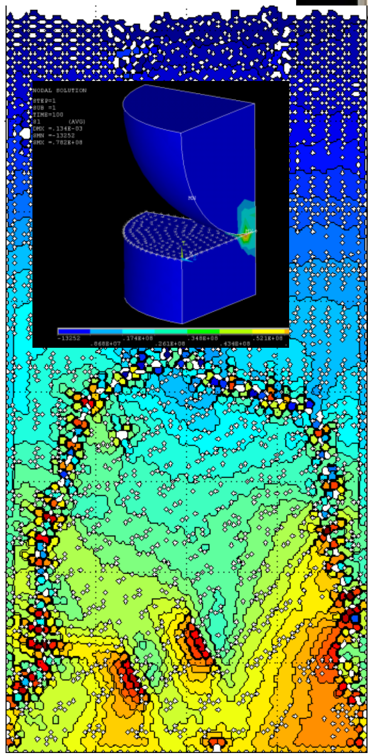


Compressed Air Energy Storages (CAES)

Current Development at DLR

- Develop tools and design solutions for optimized thermal design
- Tools and design solutions considering the thermally induced mechanical loads in large-scale packed storage (particle-discrete simulation)
- Develop design solutions for the fluid dynamic aspects (flow distribution, pressure loss)
- Reduce lifetime uncertainty of materials through extensive material testing
- Validate TES design solutions through pilot-scale testing





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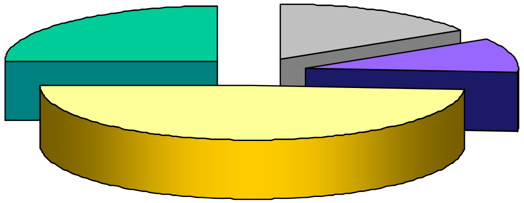
CellFlux Storage Concept

Motivation

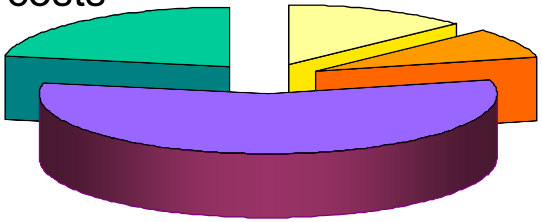
Liquid Storage Media (Molten Salt)

Solid Storage Media (Concrete)

Structure of capital costs



Molten Salt 49%



Heat Exchanger 57%

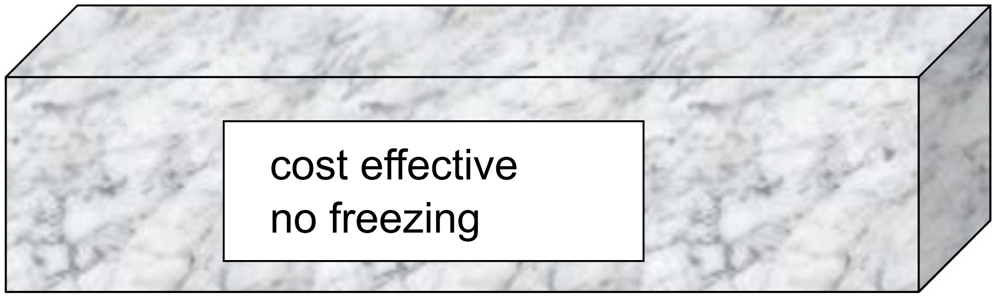
Limited potential for further cost reductions due to physical constraints

⇒ New Basis Concept required

CellFlux Storage Concept

Innovative approach

solid state storage media



Requirements

- Large heat transfer surfaces
  (short path length for heat conduction within solid storage material)
- Direct contact between storage medium and working fluid
  (no expensive piping / coating)
- Storage volume at atmospheric pressure
  (no expensive pressure vessels)

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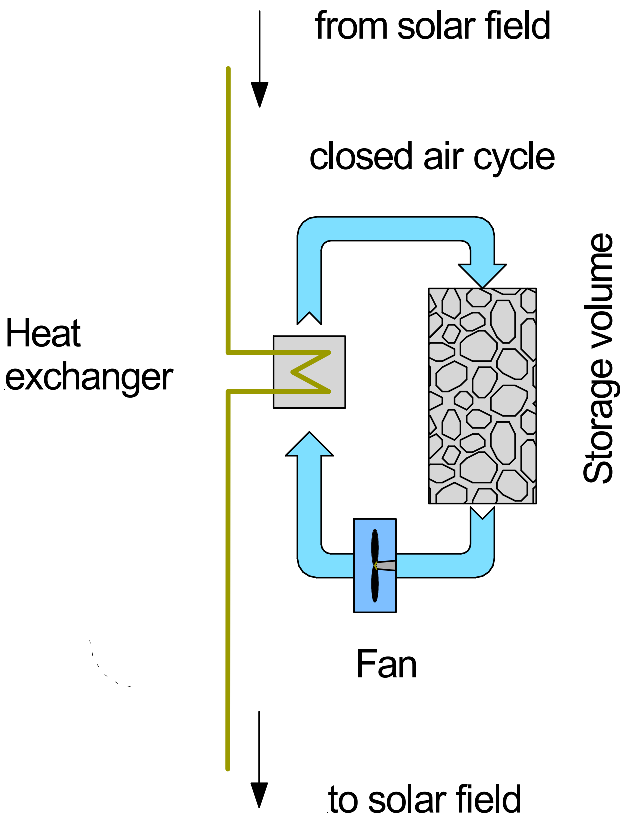
CellFlux Storage Concept

Innovative approach



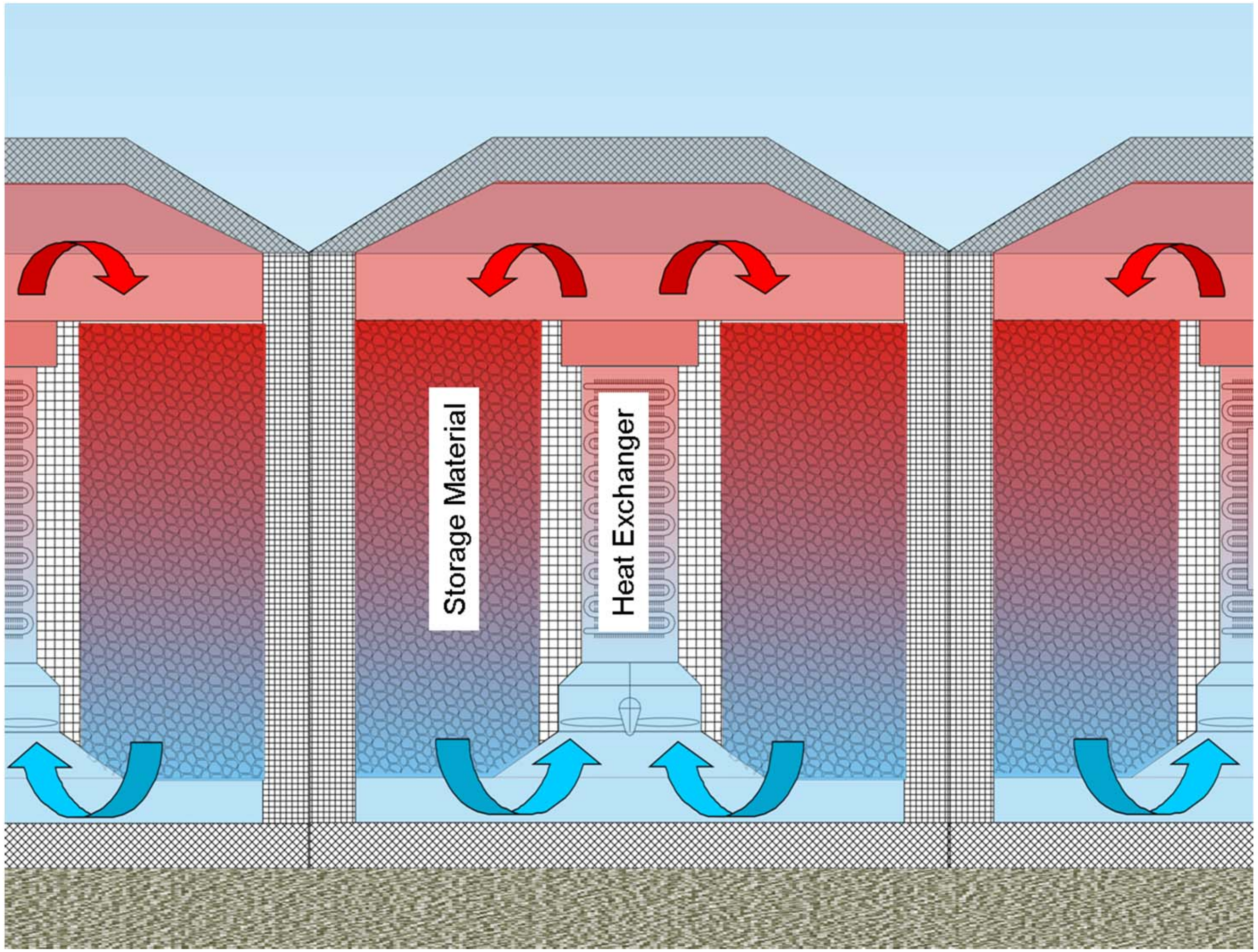
Problem:

Low volume specific energy density of air

- large pressure losses
- part load operation difficult

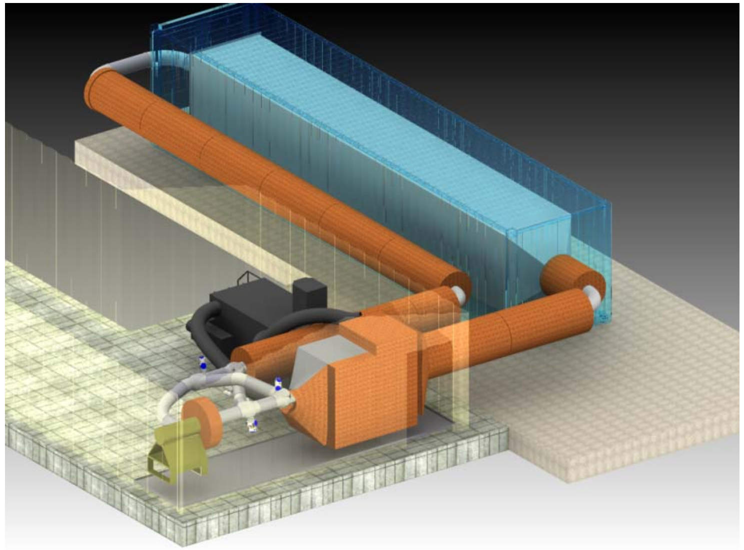
CellFlux Storage Concept

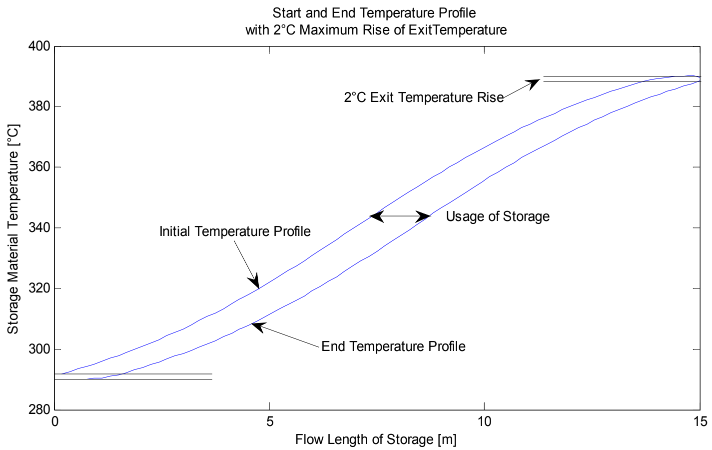
Innovative approach

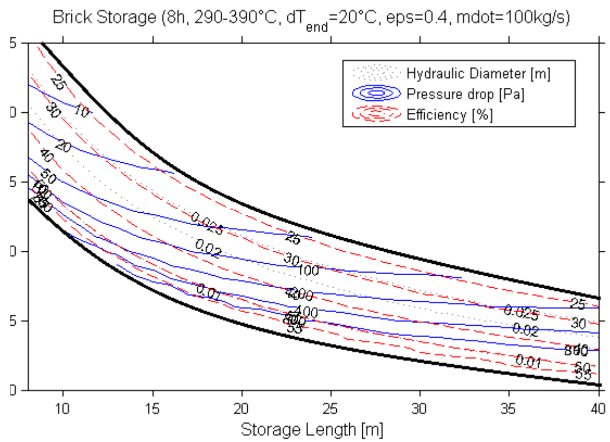


CellFlux Storage Concept
Current Development at DLR

- Theoretical and experimental investigation of sub-system behavior
- Design and construction of demonstration plant
- Development of design and sizing tools







Conclusions

- Different technical approaches for different process requirements available
- Phase change media (PCM) storages
  - Demonstration level (700 kWh)
  - Operating Temperature 300° C
  - Focus on system optimization and cost reduction
- Compressed Air Energy Storages (CAES)
  - State of the art in commercial operation
  - Optimization by use of thermal energy
  - Thermo Mechanical investigation
- CellFlux Concept
  - Proof of concept
  - Design and Optimization of components
  - System optimization